open and during the 24-hour period from 7:12 p.m., 22d, to 7:12 p.m., 23d, 11.03 billion cubic feet of water was discharged. During the flood period, from October 22 to October 27, inclusive, 42.4 billion cubic feet of water was wasted over the spillway. This represents one and one-third times as much water as that contained in the lake between elevation 80 and 87 feet.

Gatun and Pedro Miguel Lock culverts.—Gatun and Pedro Miguel Lock sidewall culverts ran from approximately 9 p. m. of the 22d to 3 p. m. of the 23d, from 11.30 p. m. of the 23d to 7.45 a. m. of the 24th, and from 6 p. m. of the 24th to 10.30 a. m. of the 25th, discharging approximately 36,000 c. f. s. and a total of 5.4 billion cubic feet during the flood period. This amount of water is equivalent to 1.2 feet in Gatun Lake.

The Mindi Dike.—A limiting controlling feature of spillway gate operation was the condition of the Mindi Dike, more than eight gates running being considered dangerous in so far as the dike was concerned. However, with 9 and 10 gates open it stood the strain and for over 2 hours held against the maximum discharge of 155,430 c. f. s. when 11 gates were running.

Telephone communications.—With the exception of the line from Alhajuela to Vigia, no break occurred in communications until about 1 p. m. of the 24th, when a landslide north of Pedro Miguel severed all telephone communications. Hardly a half hour passed before the electrical division had arranged for wireless communications and this scheme was adopted until by 6:30 p.m. a temporary line was run around the slide and communications were resumed through Gamboa. Reports were received from Gatun over the automatic line and relayed to Balboa from Gamboa. By 1 a. m. of the 25th the temporary line was replaced by permanent line, and by 4:30 a. m. direct communication with Gatun was again established.

Total yield during flood period.—The amount of water that came into Gatun Lake during the flood period can be determined only approximately, owing to the uneven surface of the lake. The following table shows these approximate figures that were obtained by using lake values at Gatun and known requirements and discharges:

Probable Gatun Lake total yield (midnight to midnight).

Date.	Billion cubic feet.	Cubic feet second.	Date.	Billion cubic feet.	Cubic feet second.
Oct. 22	10.035	116,200	Oct. 25	5.159	60,000
Oct. 23	10.238	118,500	Oct. 26	3.550	41,000
Oct. 24	15.016	173,800	Oct. 27	3.985	46,000
			Total	47.983	[1] 92,600

[1] Average.

This total represents 1½ times as much water as that contained in the lake between elevation 80 and 87 feet. It is probable that during the maximum rainy periods a momentary inflow as high as 250,000 to 300,000 c. f. s. occurred.

From a comparison of rainfall records of the flood periods of 1909 and 1923, it will be seen that over Gatun Lake the rainfall was about three times as heavy in 1923 as in 1909. This would indicate that the inflow over this region was probably three times as great as in 1909. Using this fact as a basis for a comparison of the two floods, a rough estimate of 1909 is possible. Assuming 300,000 c. f. s. as the probable 1923 flood maximum momentary inflow and knowing that approximately 100,000 c. f. s. came from the Chagres, 200,000 c. f. s. then was the inflow over Gatun Lake area other than the Chagres. If this value was three times what it was in 1909, in 1909 then 67,000 c. f. s. was the probable maximum momentary yield of the lake area. In 1909 approximately 154,000 c. f. s. was the maximum momentary yield of the Chagres above Alhajuela. 154,000 + 67,000 = 221,000 c. f. s. probable maximum momentary yield of the 1909 flood. In other words, the 1923 flood was to the 1909 flood as 300 is to 221, or roughly there was one-third more water momentarily that came into Gatun Lake during the 1923 flood than there would have been in 1909 had there been a Gatun Lake.

In using the above figures it must be remembered that at best they are only rough approximations and should be considered as such. Anyhow, it is sure that this was preeminently a Canal Zone flood as to origin. The 1909 one largely originated in the upper Chagres. It appears that a combination flood would require careful and prompt attention to protect canal structures.

IS THERE AN ANTITRADE WIND IN THE EQUATORIAL REGIONS?[1]

By Rev. S. SARASOLA, S. J.

[Observatoire National, Bogota, Colombia, Oct. 20, 1923.]

General circulation of the atmosphere.—In the discussion of the general circulation of the atmosphere writers frequently classify the winds as trade and antitrade. In the Northern Hemisphere the former blow from the northeast in the strata nearest the surface of the earth. On the other hand it is said that in the high regions of the atmosphere the antitrade winds move in the opposite direction, from the southwest, to complete in this manner the circulation of the currents.

We do not intend to study here the influences that are attributed to the earth in the deflection of the trade winds, such as the effect of the motion of rotation, nor shall we investigate the causes of those currents; our purpose is to inquire whether the observations that we have from the equatorial and tropical regions prove the existence of an antitrade in the Northern Hemisphere as has been written again and again since the meteorologis Dove advanced that theory almost a century ago.

What arguments lead the writers to verify the presence of that upper current or antitrade which blows, according to them, from the southwest? These can be summarized under two headings: 1. The direction of the smoke from some volcanoes and the ashes carried by that equatorial current; 2. The direction of the elevated currents of cirrus and cirro-stratus clouds which, as those writers affirm, must be from the southwest.

Since this observatory (*Observatorio Nacional de S. Bartolemé*, Bogota, Colombia) is situated at an elevation of 2,645 meters on the *cordillera* of the Andes and since there are available observations for almost a year in addition to those published by Rev. L. Gangoiti, S. J., director of the Observatory of the College of Belén,

[1] Translated from manuscript text in Spanish by W. W. Reed, Washington, D.C., October 30, 1923.

Havana, in the paper "*Circulación general de la atmósfera,*" we have believed it opportune to analyze those data to see if in reality the theory of the antitrade is based upon indisputable facts. It is to be noted that the books on meteorology contain categorical statements, but do not give data that confirm them.

Arguments against the antitrade wind.—To prove the existence of the upper antitrade wind the writers refer to the ashes that the volcanoes have thrown out in some eruptions, instances of which are given, for example, in the work on meteorology by A. Angot. This argument is very much lacking in force, since the data are very few.

Moreover, various observations of this phenomenon prove entirely the contrary; that is, that the antitrade, or the equatorial current of Dove, does not exist.

With reference to the volcano Cotopaxi a letter written by Father Sodiro, S. J., to the director of the Belén Observatory merits attention.

"The eruption began about 6 a. m. on the 26th of June (1877), hurling up a black column which on account of the stillness of the atmosphere rose vertically to the height of 8,000 to 9,000 meters above the level of the crater. Thence through a current of air that was moving from the east it was directed toward the western *cordillera*, but the fine dust that formed a dense cloud began to darken the air to a great distance from the volcano. At 8 a. m. the wind suddenly changed and blew toward west-northwest; the cloud of dust which until then filled the atmosphere only to the south of Quito was reaching that city. At that hour the darkness in Quito was that of the beginning of a night without moonlight; at 2 p. m. there was complete darkness, and between 3 p. m. and 4 p. m. it was such that one could not see his hand before him and people were stumbling against one another in the streets. The light from the street lamps extended hardly to a distance of 2 meters.

"This darkness and the ashes that caused it extended from the southwest to the northwest of the volcano; in Ambato (75 miles south of Quito) there was observed only the immense cloud which extended over the Province of Leon and reached toward the west as far as the Pacific Ocean."

If it is added that on not a few days in 1907 and 1908 the smoke from the volcano of Cotopaxi moved from the second quadrant and occasionally from the west we shall be of the opinion that the eruptions of the Ecuadorian volcano do not prove the existence of the antitrade wind.

Nor does the volcano of Colima (in Mexico), which has an altitude of 3,960 meters, throw its smoke from the southwest. During almost nine months the prevailing current is from the second or from the fourth quadrant, only in March and sometimes in February is it from the southwest.

And what is to be said of the result obtained from the observations of the highest clouds? It is true that the data for Bogota embrace hardly an entire year, but just like those for the other points these confirm the same conclusion, namely, that the upper antitrade does not exist. Let us summarize these observations.

Observations in Ecuador and the tropical regions.—We begin with those made at Quito made by Father Harbach, S. J., who noted the direction of the cirrus clouds for 38 months. Also at Riobamba and Pifo observations of the highest clouds were made in the years 1908, 1909, and 1910. The result that is derived from all these in that indicated by Father Gangoiti in his paper.

Quito and Riobamba are in fact in the Southern Hemisphere, but here they can be considered in the Northern Hemisphere, since at both places the upper current from the northwest or southwest ceases to be dominant, the cirrus clouds moving by far most frequently from the first quadrant and with decreasing frequency from the second, fourth, and third quadrants. Father Herbach stated in one of his letters that the cirrus clouds move from the northeast almost without exception during the entire year.

We are of the opinion, then, that this current of the antitrade does not exist in the limits of Ecuador as many writers have theoretically supposed.

Observations at Bogota.—In the observations made every two hours for one year at the new *Observatorio Nacional de S. Bartolomé* very careful study has been given to the directions of the cirrus and cirro-stratus clouds, also to those of the intermediate and lower clouds. The elevation of the observatory above sea level is 2,645 meters. Here is the result of the observations.

In the months of October, November, and December the upper currents move from the third quadrant very rarely; in the following months they have this direction somewhat more frequently. On the contrary the frequency with which they move from the second quadrant is rather great, and there is a tendency toward movement from south, especially in the month of March. Hence neither do the observations at Bogota give us sound arguments in favor of the antitrade.

The reader will desire, perhaps, to know what dircetion the intermediate and lower clouds have on this *cordillera* of the Andes. It can be stated that in this region of the atmosphere, too, the usual currents move from the second quadrant, although they sometimes undergo slight deviation. In the rainy season the winds nearest the surface shift somewhat, blowing from the west at the approach of the squalls.

What is to be said of the atmospheric circulation observed in the subtropical regions extending to the north of Colombia? If we analyze the nephoscopic data published in Washington and the studies that we have relative to the highest currents over the islands of the Caribbean Sea, comparing at the same time the cyclonic and anticyclonic circulations, we shall be of the opinion that even here there do not exist convincing arguments in favor of the upper current known by the name antitrade.

From the data on the upper currents furnished by the Weather Bureau at Washington and relating to nephoscopic observations the following conclusions may be reached.

On the island of Trinidad the highest clouds move approximately from the west during the months January to May, inclusive, November, and December, and from the east during the hurricane season. The westerly current is most constant at Curaçao, where the clouds move from the easterly direction only in the months of July and August.

Also in the Barbados, Dominica, and St. Kitts the current is at times from the west, but not from the southwest. According to Maxwell Hall the cirrus clouds

move from east-northeast in the hurricane season. We shall not omit mentioning the direction that the upper clouds have at San Juan, Porto Rico. In general it can be stated that the current from the second quadrant predominates, the times at which the southwest direction is observed being relatively few.

There will hardly be found a series of observations of clouds so extended and so complete as that of the observatory at Belén College, Havana. The currents of the atmosphere have been observed very carefully at intervals of two hours during a period of 50 years or more.

In the paper that its director, Father Gangoiti, published in 1904 we find the following results for the period 1892–1902.

Mean direction of upper clouds at Havana, from the observations for 11 years (1892–1902).

	Cirrus.	Cirro-stratus.		Cirrus.	Cirro-stratus.
January	S. 81 W.	S. 79 W.	July	N. 28 E.	N. 52 E.
February	S. 83 W.	S. 80 W.	August	N. 48 E.	N. 54 E.
March	N. 88 W.	S. 89 W.	September	N. 27 E.	N. 89 E.
April	N. 89 W.	S. 89 W.	October	N. 87 W.	S. 61 W.
May	N. 83 W.	S. 84 W.	November	S. 77 W.	S. 72 W.
June	N. 49 W.	N. 84 W.	December	S. 80 W.	S. 73 W.

Conclusion.—There do not exist sound arguments in favor of the theory of the antitrade wind as advanced by many writers. In the observations in Ecuador, Bogota, Mexico, and the Antilles that upper current is not found to be constant and permanent.

THE DEVELOPMENT OF METEOROLOGY AS ILLUSTRATIVE OF THE RÔLE OF MATHEMATICS IN THE PROGRESS OF SCIENCE.[1]

By EDGAR W. WOOLARD.

[Weather Bureau, Washington, D. C., Dec. 10, 1923.]

Mathematics plays a singularly fundamental rôle in all domains of exact scientific thought. In the words of Spottiswoode,[2] "Conterminous with space and coeval with time is the kingdom of Mathematics; within this range her dominion is supreme; otherwise than according to her order nothing can exist; in contradiction to her laws nothing takes place. On her mysterious scroll is to be found written for those who can read it, that which has been, that which is, and that which is to come." An irrefutable proof of this claim is provided by an analysis of the rôle which mathematics has actually played in the development of the sciences,[3] and in the present paper we shall use the history and present status of the science of Meteorology as an illustration.

Man quickly finds by experience that his greatest good and comfort come from an understanding of the environment in which he finds himself—as Bacon said, Knowledge means power and control over Nature; besides, he naturally feels an innate longing to know the explanations of the phenomena that he sees going on about him.[4] Hence the very beginnings of natural science are found among the great nations of remote antiquity—the Egyptians, Assyrians, and Babylonians.

Atmospheric phenomena must have been among the first to attract attention, and meteorology, as a branch of knowledge, is probably as old as mankind, particularly since in early times primitive man lived largely in the open, as hunter or agriculturist, and was forced to watch the weather closely for the sake of his own welfare.[5] Weather lore existed among the Chaldeans and the Babylonians two or three thousand years before the Christian era.

The first major period in the history of meteorology may be taken to be that from antiquity to about 1600 A. D. Early knowledge was cultivated only for immediate practical needs, and in very primitive times the mere observation of facts without inquiry as to causes was as far as it was carried; such knowledge does not constitute true science: We must generalize from our observations; the ultimate goal of scientific research is the discovery of fundamental and comprehensive laws, and the demonstration of how the phenomena and their laws result from a few simple underlying principles. Simple generalizations were made at an early stage by the ancients, but it was left to the Greeks to initiate abstract thought and to invent explanatory hypotheses. Greek thought culminated in the great system of Aristotle (384–322 B. C.), who gathered together and systematized all knowledge then existing, and subdivided Science, which at that time was only a part of Philosophy, into various special subjects. Aristotle's *Meteorologica* [6] was the first treatise on meteorology. Outside of the activities of the Alexandrian School, the Arabs, and the Moors, there is little to record in the history of any science during the ensuing 2,000 years of scholasticism and introspection.

Early science accepted its hypotheses without any adequate verificatory inquiry—its explanations did not have to explain more than they were directly invented to explain, and they did not have to cohere with previously acquired knowledge nor be able to predict undiscovered facts; much of this "science" was therefore quite fantastic. The *modern* trained man of science "uses his powers of observation to discover the facts of nature, his inventive ingenuity to propose various possible hypotheses for the explanation of the facts, his power of logical reflection to think out, or deduce, from each hypothesis, in accordance with previously acquired, pertinent knowledge, just what ought to happen if the hypothesis were true, and his impartial faculty of verification to decide which hypothesis, if any, is competent to explain the observed facts;" [7] and he must constantly be on his guard against the numerous errors that may creep in at any stage of the procedure. In the sixteenth century there was a general reconstruction and reorganization of thought; modern methods in science began with Galileo, and the complete Scientific Method came into prominence under the leadership of Francis Bacon (1561–1626). In philosophy, a reaction "back to nature" took place, away from the barren scholasticism of the Middle Ages; the special sciences left the philosophic fold, and became differentiated one from another; the great geographical discoveries of the fifteenth and sixteenth centuries, and the revolution in astronomy occasioned by the work of Copernicus (1473–1543) and Kepler (1571–1630), contributed to a broadening of man's mental horizon that ushered in a new area.

The second major period of meteorological history is that from 1600 to about 1800. The first essential in any

[1] Presented before the Fourteenth meeting of the Maryland-Virginia-District of Columbia Section of the Mathematical Association of America, Annapolis, Md., December 8, 1923.

[2] Wm. Spottiswoode: Presidential address before the British Association. *Rept. Brit. Assoc. Adv. Sci., Dublin, 1878.* pp. 1–32. London, 1879.

[3] See R. D. Carmichael: The provision made by mathematics for the needs of science. *Science*, (N. S.), 45, 465–474, 1917.

[4] *Cf.* R. D. Carmichael: Motives for the cultivation of mathematics. *Scientific Monthly*, 8, 160–178, 1919.

[5] See G. Hellmann. The dawn of meteorology. *Quar. Jour. Roy. Met. Soc.*, 34, 221–232, 1908.

[6] See E. W. Webster: The works of Aristotle translated into English: *Meteorologica*. Oxford, 1923.

[7] W. M. Davis: The reasonableness of science. *Scientific Monthly*, 15, 193–214, 1922.